The role of different cues in the brain mechanism on visual spatial attention*

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Abstract The visual spatial attention mechanism in the brain was studied in 16 young subjects through the visual search paradigm of precue-target by the event-related potential (ERP) technique, with the attentive ranges cued by different scales of Chinese character and region cues. The results showed that the response time for Chinese character cues was much longer than that for region cues especially for small region cues. With the exterior interferences, the target stimuli recognition under region cues was much quicker than that under Chinese character cues. Compared with that under region cues, targets under Chinese character cues could lead to increase of the posterior P1, decrease of the N1 and increase of the P2. It should also be noted that the differences between region cues and Chinese character cues were affected by the interference types. Under exterior interferences, no significant difference was found between region cues and Chinese character cues; however, it was not the case under the interior interferences. Considering the difference between the exterior interferences and the interior interferences, we could conclude that with the increase of difficulty in target recognition there was obvious difference in the consumption of anterior frontal resources by target stimuli under the two kinds of cues.

Keywords: visual spatial attention, cue scale, event-related potential (ERP), Chinese character cues, region cues.

In the experiments of spatial cues, there are two main kinds of cues: central cues, for instance Chinese character cues and peripheral cues, and peripheral cues, for instance region cues. The former is thought to activate the interior attentive system, but the latter is to activate the exterior attentive system. Generally speaking, the former evokes slow, controllable and voluntary attentive distribution, but the latter attracts attention in a rapid, automatic and involuntary way[1,2].

However, it has been found that their effects are not totally independent. Nougier et al.[3] have found that the auto-orientation effect evoked by peripheral cues is modulated by the voluntary attentive processing evoked by central cues. Warner et al.[4] pointed out that the two kinds of cues could evoke consistent or similar brain mechanisms though they had different pathways.

Lu and Dosher[5] found that, compared with cues which appeared at the same position of targets at the same time, 100% effective central cues improved the threshold of high-level exterior interferences but did not improve the threshold of low-level interior interferences, and peripheral cues improved the threshold of both high-level and low-level exterior interferences. The finding indicated that exterior and interior attentive systems could evoke different brain mechanisms: as for the interior attentive system, the exterior interferences were excluded; as for the exterior attentive system, the exterior interferences were excluded and the attentions to stimuli strengthened.

Many event-related potential (ERP) studies about visual spatial attention found that, under central cues, attention and the effectiveness of cues evoked larger posterior P1 and N1 components, demonstrating the mechanism of attention improved perception[6,7]. However, the results of region cues were different and inconsistent.

With a relatively long "cue-target" interval,

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Hillyard et al.[8] found that under region cues the early attentive regulation was represented by the enlarging of N1 but not P1.

Fu et al.[9] reported that effective region cues could enlarge P1 and N2. Meanwhile, effective cues would delay the latency of P1 and N1 on the opposite side. N1 on the opposite side was enlarged under ineffective cues. And the latency and amplitude of P2 were also modulated by the effectiveness of cues.

The effect of interferences has not been taken into account in previous research. We had previously found that the interference stimulation significantly affected the early ERP effects in visual spatial attention by the Chinese character centre cues[10—12]. Then what effect would region cue and Chinese character cue have on the recognition of target stimuli with interferences? Would such an effect affect early ERP components evoked by perception and their features? This study aimed to answer these questions.

1 Methods

1.1 Subjects

Sixteen healthy participants (8 males and 8 females, aged 19—24 with an average of 21) attended the electrophysiological experiment for the first time. They were right-handed, and had normal or corrected-to-normal vision.

1.2 Stimuli

The stimuli were presented on the computer screen. A complete trial was "background-cue-target". The background was comprised of three homocentric white circles (Fig. 1).

The cues were three Chinese characters: "大", "中", "小". The region cue was composed of three circles, their visual angle was 8.6°, 5.7°, 2.9°, respectively.

During the large region cue, the target stimuli "T" will present in the large circle (8.6°) while the other two interference stimulations present in the medium and the small circles in the opposite visual fields. During the medium region cue, "T" presents in the medium circle (5.7°) while interferences present in the large and the small circles on the opposite side. During the small region cue, "T" presents in the small circle (2.9°) while interferences present in the large and the medium circles on the opposite side.

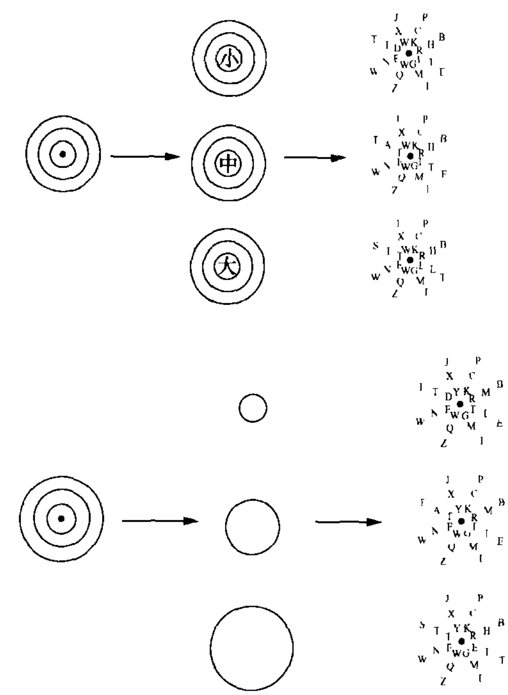

Fig. 1. Sketch map of the experimental model: Chinese character cues (upper) and region cues (lower).

1.3 ERP recording

The electroencephalogram (EEG) was recorded from 64 scalp sites using tin electrodes mounted in an elastic cap (NeuroScan ERP Work Station), with the linked reference on the left and right mastoids. The vertical electrooculogram (EOG) was recorded with electrodes placed above and below the left eye. All inter-electrode impedance was maintained below 5 kΩ. The signals of EEG and EOG were amplified using a 0.1—40 Hz bandpass and continuously sampled at 500 Hz/channel for off-line analysis. ERPs were averaged over a 500 ms epoch including a 100 ms prestimulus baseline. Trials with artifacts (mean voltage exceeding ±100 μV) were excluded from averaging.

1.4 Procedure and task

The stimuli sequences in the experiment included Chinese characters as cues and region as cues. At first the background was presented for 300 ms, and then the cue was presented for 300 ms. Then the target stimuli, e.g. three circles which were comprised of 24 characters, were presented for 1500 ms. The interval between the cue and target was 400—600 ms randomly. The tasks of the subjects were to search the target character "T" within the effect range appearing in the left or right visual field according to the cues. If "T" appeared in the left or right visual field, they were asked for pressing the left or right button. The subjects should do this both correctly and quickly. The chance of character "T" appearing in left or right visual field was equal. And there were 10% stimuli lack of target stimuli and interferences.

1.5 ERP data analyses and statistics

The analyses of the behavioral data in cue type (2 levels: Chinese characters cue and region cue) and region cue type (three levels: large medium small) were performed using the ANOVA software.

The overlap of early ERP components between cue and target under the short interval condition was eliminated using the ADJAR method. The overlapping times ranged from 45 to 68 times with an average of 55 times. According to the purpose and the wave features of the grand averages, the following 14 sites were chosen for statistical analysis: POZ, PO3, PO4, PO5, PO6, PO7, PO8 (7 sites for posterior) and Fz, F1, F2, F3, F4, F5, F6 (7 sites for anterior). ERPs were analyzed at the posterior scalp at 50—160 ms (P1), 161—220 ms (N1), 221—290 ms (P2), and 291—390 ms (N2). ERPs were analyzed at the anterior scalp at 90—180 ms (N1), 181—270 ms (P2), 271—370 ms (N2). The descriptive data were presented as "mean ± SE". The latencies and amplitudes of the ERP components above were analyzed by three-way repeated measures analyses of variance (ANOVA). The ANOVA factors were cue size (3 levels: large, medium and small) and electrode sites (7 sites each for anterior and posterior components respectively). The P values of ANOVA were corrected using the Greenhouse-Geisser method.

2 Results

2.1 Behavioral data

With the increase of cue ranges, the response time of target stimuli recognition under Chinese characters attention region and region cues became much longer ($F_{1,15} = 15.17$, $p < 0.001$) under the two kinds of cues.

The correct ratio of target stimuli recognition under region cues increased with the increased of ranges, but the correct ratio of target stimuli recognition under "大" as cues decreased; the main effects of the response time under Chinese characters as cues were significant ($F_{2,30} = 13.03$, $p < 0.001$); and so as the region cues ($F_{2,30} = 12.15$, $p < 0.001$).

Under the three kinds of region cues, the response time under Chinese character cues was much longer than that under region cues especially under small region cues (longer than 100 ms); however, the difference in correct ratio was significant merely under large cues, that is, the correct ratio under Chinese character cues was lower than that under region cues (Table 1).

Table 1. Behavioral data

	Correctness(%)		Response time(ms)	
	Chinese characters	Region circles	Chinese characters	Region circles
Small	80.61±10.67	81.32±11.38	777.98±17.25	671.09±18.32
Medium	89.45±8.11	90.54±10.73	829.67±22.64	787.56±31.14
Large	83.72±9.99	93.89±7.42	982.34±25.12	922.33±26.78

2.2 Scale effect of Chinese characters

Anterior N1: There were significant cue range main effects ($F_{2,30} = 14.35$, $p < 0.001$). Under small cues, the amplitudes of N1 evoked by target stimuli were the highest (Fz: -3.91 ± 0.68 μV), those under medium cues were lower (-2.98 ± 0.47 μV), and those under large cues were the lowest (-2.06 ± 0.54 μV).

Anterior P2: The scale effects were significant ($F_{2,30} = 10.28$, $p < 0.01$), but their appearance was different from that without interferences, that is, the amplitudes of the anterior P2 under small cues and medium cues were identical, and both of them were larger than those under large cues.

Posterior P1: There were main scale effects in P1 amplitudes ($F_{2,30} = 11.67$, $p < 0.001$), and their appearance was similar to that without interferences. There were also significant main effects in latency ($F_{2,30} = 5.97$, $p < 0.05$), that is, the latency under large cues (PO4: 96 ± 5.71 ms) was shorter than that under small cues (108 ± 6.86 ms) (Fig. 2).

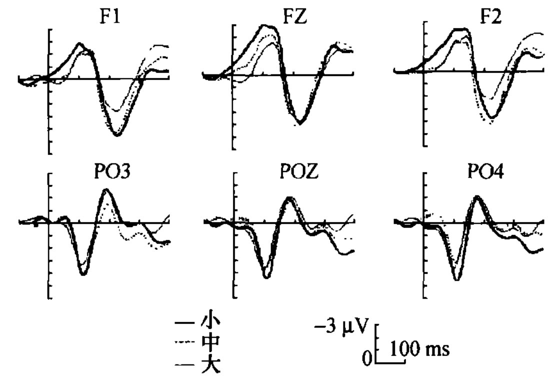

Fig. 2. General average of ERP obtained by the Chinese character cues.

2.3 Scale effect of region cues

There were significant main effects in the amplitudes of ERP components P1 and N1 under region cues (P1: $F_{2,30} = 8.76$, $p < 0.01$; N1: $F_{2,30} = 11.16$, $p < 0.001$), but the appearance was different from that under Chinese character cues.

There was no difference in the amplitude of anterior N1 under large and small ranges ($F_{1,15} = 3.56$, $p > 0.05$), which was larger than that under medium ranges. However, there was no difference in the amplitude of P2 under medium and small ranges ($F_{1,15} = 3.12$, $p > 0.05$), which was larger than that under large ranges. The appearance of posterior P1 was similar to that of anterior P2, that is, there was no difference in the amplitude of posterior P1 under medium and small ranges ($F_{1,15} = 4.03$, $p > 0.05$), which was larger than that under large ranges. However, the appearance of posterior N1 was similar to that of anterior N1, that is, there was no difference in the amplitude of anterior N1 under large and small ranges, which was larger than that under medium ranges (Fig. 3).

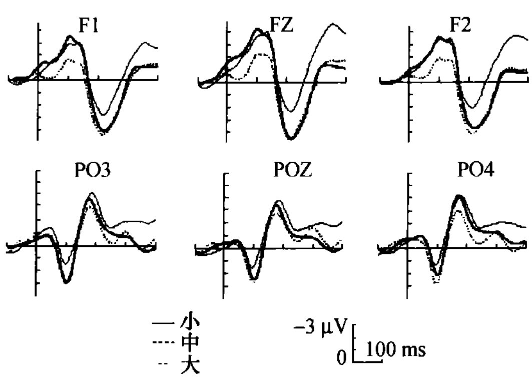

Fig. 3. General average of ERP obtained by the region cues.

2.4 Comparisons between ERP components evoked by Chinese character cues and region cues

Anterior N1 and P2 components: There were significant cue type main effects in the anterior N1 and P2 components evoked by target stimuli under the two kinds of cues (N1: $F_{1,15} = 15.23$, $p < 0.001$; P2: $F_{1,15} = 9.83$, $p < 0.01$), and the interactions between cue types and cue scales were significant (N1: $F_{2,30} = 8.16$, $p < 0.01$; P2: $F_{2,30} = 8.11$, $p < 0.01$). As for the cue types and the features of ERP changes of different scales, the target stimuli under region cues could evoke larger N1 components, especially at Fz; however, the target stimuli under Chinese character cues could evoke larger P2 components.

Posterior P1 and N1 components: There were significant cue type main effects ($F_{1,15} = 11.43$, $p < 0.01$; $F_{1,15} = 10.79$, $p < 0.01$), and the interactions between cue types and cue scales were significant (P1: $F_{2,30} = 9.33$, $p < 0.01$; N1: $F_{2,30} = 10.03$, $p < 0.01$). As for the cue types and the features of ERP changes of different scales, the target stimuli under Chinese character cues could evoke larger posterior P1 components; however, the target stimuli under region cues could evoke larger posterior N1 components (Fig. 4). The topography of ERP components evoked by target stimuli under two kinds of cues is shown in Fig. 5.

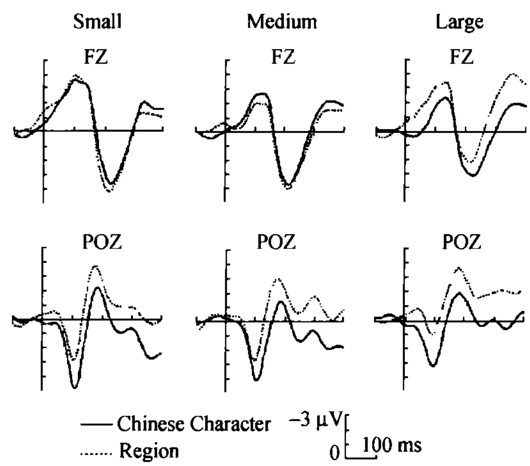

Fig. 4. Comparisons between ERP components evoked by Chinese character cues and region cues.

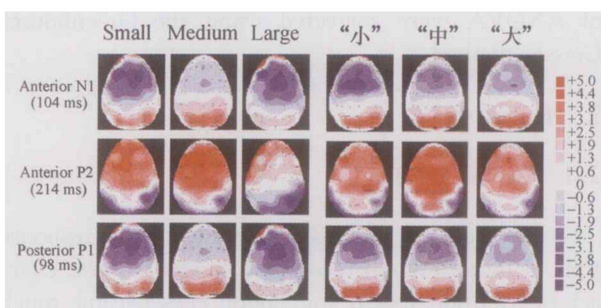

Fig. 5. The topography of ERP components evoked by Chinese character cues and region cues.

3 Discussion

In this experiment, the attentive range scales were strictly paralleled under two kinds of cues, so that the comparison of brain mechanisms involved in Chinese character cues and region cues could be easily carried out. In the experiment, the interferences were outside the cue ranges (in the medium and large circles) under small cues, which could be regarded as "exterior interferences"; under large cues, the interferences were within the cue ranges (in the medium and small circles), which could be regarded as "interior interferences", as to medium cues, there were two kinds of interferences.

There were significant cue range scale effects under region cues and Chinese character cues, that is, with the increase of cue ranges, the response time became longer, which means that interior interferences could make target stimuli recognition slower than exterior interferences, and this is similar to the findings under Chinese character cues. In the pervious study about peripheral cues and central cues, processing advantages appeared in short intervals, while advantages became weaker or disappeared in long intervals[13]. The response time of Chinese character cues was significantly longer than that in range cues which demonstrated that range cues could increase the speed of target stimuli cognition or visual scan. Under small cues, such advantages were even more obvious, which meant that the advantages of region cues were affected by the features of interferences (interior interferences or exterior interferences), that is, with exterior interferences, the target stimuli recognition under region cues is much quicker than that under Chinese character cues.

The ERP findings of the experiment indicated that, under both kinds of cues, there were significant scale effects, but their appearance was different. As to posterior P1, the difference mainly lied in medium region cues, that is, compared with Chinese character cues, region cues narrow the difference between medium ranges and small ranges while enlarge the difference between medium ranges and large ranges; as to anterior N1, region cues narrow the difference between large ranges and small ranges whereas wide the difference between medium ranges and large ranges. These findings indicate that region cues and Chinese character cues might have different early processing mechanisms. Meanwhile, there was no difference in anterior N1 under large ranges and small ranges, illustrating that under region cues, the resources mobilized by anterior frontal areas at the early perception processing with exterior and interior interferences were similar; however, under Chinese character cues, there were differences in the consume of psychological resources.

Apart from the differences in scale effects discussed above, the comparison was made between the ERP features under region cues and Chinese character cues, and the findings were very constructive, which further detail the difference in the two mechanisms.

At first, compared with region cues, the target stimuli under Chinese character cues could lead to the increase of posterior P1 and inhibition of N1.

After the processing of cue stimuli, the subjects needed to match the target stimuli range and the cue range. Because the interval between cue and target stimuli was very short, the processing of Chinese characters was not as good as that under region cues, and this could encourage the further processing of meaning, that is, more resources were needed than region cues, which was reflected by the increase of P1. Posterior N1 might reflect the distribution mechanism of attention[6—14]. Under Chinese character cues, fewer resources were allocated to target stimuli recognition, so N1 decreased. Moreover, there were obvious differences in anterior N1 and P2, that is, N1 amplitudes evoked by target stimuli under Chinese character cues were smaller than that under region cues; as for P2, it was the other way round. To some degrees, the anterior N1 reflected the processing of anterior frontal areas in perception[15,16]. Therefore, as a kind of interior cues, interior attentive system was excited with Chinese character cues. At the early stage of perception, very few neurons were activated, and the use of anterior frontal area resources was not enough. It was found in previous studies that compared with central cues, region cues could evoke quicker behavioral reactions and attract more attention, and were not so easy to be influenced by interferences. This is consistent with our findings.

It should also be noted that the difference between region cues and Chinese character cues is affected by attentive ranges, that is, it is affected by interference types, which is mainly reflected in anterior N1 and P2. Under small region cues (exterior interferences), no significant difference is found between region cues and Chinese character cues; however, it is not the case under large region cues (interior interferences). Considering the difference between exterior interferences and interior interferences, we conclude that, with increasing of difficulty in target recognition, there is obvious difference in consumption of the anterior frontal cortex resources by target stimuli under the two kinds of cues.

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